245

EFFECT OF SUBSOILING AND THE DEEP PLACEMENT OF K ON ROOT GROWTH AND SOIL WATER DEPLETION BY COTTON

G.L. Mullins, D.W. Reeves, C. H. Burmester, and H. H. Bryant, Associate Professor, Research Agronomist, Extension Agronomist, and Research Specialist, respectively, Department of Agronomy and Soils, and USDA-ARS, National Soil Dynamics Laboratory, Auburn University, Auburn AL.

Abstract

A study was conducted in 1990 and 1991 to evaluate root development and water use by cotton as affected by in-row subsoiling and the placement of K fertilizer. Measurements were taken from an ongoing field experiment established in 1989 to evaluate cotton response to the deep placement of K fertilizer. The experiment was located in central Alabama on a Norfolk fine sandy loam. For this study, 5 treatments were compared: 1) check without subsoiling, 2) check with in-row subsoiling, 3) 90 lb K_2O A^{-1} surface applied without in-row subsoiling, 4) 90 lb K_2O A^{-1} surface apppied with in-row subsoiling, and 5) 90 lb K_2O A^{-1} deep placed, in-row. Penetromenter readings taken in 1991 showed the soil has a well developed traffic pan at a depth of approximately 6-15 inches. The readings also show that in-row subsoiling disrupted the pan up to 10 inches away from the in-row position. Soil water and root density measurements taken in-row showed that water uptake and root growth at depths >8 inches were improved by subsoiling and the application of K fertilizer. Water depletion and root density at depths > 8 inches were generally greater for the treatment reciving the deep applied K. However, the application of K on the surface in combination with in-row subsoiling resulted in the highest whole plant weight, leaf surface area and seed cotton yield. Higher yields for the surface application of K with in-row subsoiling probably resulted since the surface applied K was exposed to a larger proportion of the cotton root system as compared to the in-row, deep placed K.

Introduction

Evaluating crop response to the deep placement or deep incorporation of dry fertilizer has been the subject of numerous studies (3, 4, 5, 6, 8, 9, 10, 16, 17, 18, 19). The results of this work show that under suitable conditions, improvements in crop yields and root developement can be obtained. Woodruff and Smith (19) reported that for a claypan soil, shattering of the subsoil in combination with subsoil mixing of limestone and a NPK fertilizer increased corn yields and improved root growth of sweet clover. More recently, Gonzalez-Erico et al. (6) looked at corn response to deep incorporation of limestone on an Oxisol. They reported that incorporation of limestone to a depth of 30 cm improved corn root growth, increased water utilization, and increased grain yields. Similar results with corn and cotton were obtained when limestone was incorporated to depths up to 45 cm in two Ultisols in Alabama (4). Woodhouse (18), in contrast, did not see any improvement in yield of a lespedeza-Dallisgrass mixture on a Cecil sandy loam as a result of plow sole applications of lime, TSP and muriate of potash. Reeves et al. (10) did not observe any benefits to grain sorghum grown on two Ultisols in Alabama as a result of injecting a lime suspension into the subsoil.

Research recently conducted in Mississippi has shown promising results for increasing cotton yields by deep placement of dry fertilizer into the subsoil (16, 17). In this work the fertilizer is deep placed as a band into the subsoil behind a subsoiler shank. Increases in lint yield by as much as 100 lb A^{-1} have been reported on soils having low available K in the subsoil.

At present, the mechanisms involved in producing a positive cotton yield response to the deep placement of K have not been quantified. If a positive response does occur, it would most likely be due to increased K availability in the subsoil. In addition, deep placement of K may influence cotton root growth within the zone of placement. Effects on root growth, either positive or negative, due to deep placed K would affect the entire plant by altering water and nutrient uptake. Khasawneh and Copeland (7) showed that increasing soil P results in an increase in cotton root growth. Preliminary work with band application of K on Acala cotton (1), however, suggests that cotton root length and root surface area is insensitive to K fertilization.

The objectives of this study were 1) determine the effect of subsoiling on plant growth and yield, soil water extraction and root growth of cotton and 2) determine the effect of K fertilizer placement on cotton growth and yield, root growth and soil water extraction.

Materials and Methods

A series of field studies was initiated in 1989 to evaluate cotton response to the deep placement of K fertilizer and agricultural limestone on Alabama soils. One of the study sites included a Norfolk fine sandy loam (Typic Kandiudults) located in central Alabama. The soil had a "medium" soil test rating for K in the top 0-6 inches of soil (Table 1) and a "low" soil test rating at greater depths.

Annual treatments consisted of rates of K broadcast on the surface with and without in-row subsoiling, or deep placed in the subsoil channel. Deep placement of fertilizer and subsoiling were accomplished using the two-row deep fertilizer applicator described by Tupper and Pringle (15). A complete description of the treatments and the yield data for 1989 and 1990 were presented by Mullins et al. (8). For this study, data were collected from selected treatments (Table 2). The 5 treatments evaluated for this study were: 1) check without subsoiling, 2) check with in-row subsoiling, 3) 90 lb K_2O A^{-1} surface applied without subsoiling, 4) 90 lb K_2O A^{-1} surface applied with in-row subsoiling, and 5) 90 lb K_2O A^{-1} deep placed, in-row. The variety used in this study was Deltapine 50.

Soil volumetric moisture content was measured at three depths in each plot. Parallel paired stainless steel rods 0.25 inches in diameter were installed in-row at three depths (8, 16, and 32 inches). A Tektronix 1502B TDR cable tester was used to measure soil water using the time-domain reflectrometry (TDR) method as developed by Topp (13, 14). In 1989, measurements were taken 6 times, beginning on 21 August and ending 11 September. During 1991, measurements were taken 8 times, beginning on 22 July and ending 19 August.

In 1990 and 1991, cotton yields were determined by mechanically picking the two center rows from each plot. Immediately after cotton harvest, soil cores (1.25 inches in diameter) were collected in-row to a depth of 32 inches. Two soil cores were collected per plot adjacent to the paired steel rods. Cores were subdivided into increments of 0-8, 8-16, and 16-32 inches. Roots were quantitatively separated from the soil cores using a hydropneumatic elutriation system (11; Gillison's Variety Fabrication Inc., Benzonia, MI). Root length was determined by the line intersect method (12). The root length data were combined with the volume of the soil cores to calculate root length density. Soil cores were collected to avoid tap roots, thus only branch roots were measured.

Soil penetrometer recordings were made in 1991 at one month after planting. The readings were taken when the soil moisture content was near field capacity (shortly after a heavy rain). Five penetrations were made at five different positions within each plot to a depth of 20 inches. The five positions were: 0, 5, 10, 15, and 20 inches away from the in-row position. Penetrations were made in non-trafficked rows. Measurements were made using a hand held Bush recording soil penetrometer (Mark 1 Model 1979; Findlay, Irvine Ltd., Penicuik, Scotland).

On 27 August, 1991, four intact cotton plants were harvested by plot. Harvested plants were separated into stems, leaves, and bolls, dried and weighed. Prior to drying, the leaves were rated for K deficiency symptoms and measured for total surface area. Leaves were given five deficiency ratings: 1) dead, 2) severe, 3) moderate, 4) slight, and 5) healthy leaf. The leaf surface area and the potassium ratings were used to determine a leaf health index (LHI). Leaf health index was calculated as the leaf surface area after weighting the leaf surface area based on the severity of K deficiency. Weight factors were: 5, healthy leaf; 4, slight deficiency; 3, moderate deficiency; 2 severe deficiency; 1, dead leaves.

Results and Discussion

During 1990 and 1991 there were no effects ($P \leq 0.10$) of in-row subsoiling or K fertilizer treatments on the volumetric soil moisture content of the top 8 inches of soil (Fig. 1). In 1990, the treatment receiving 90 lb K_2O A^{-1} deep placed, had the lowest volumetric moisture content at a depth of 8-16 inches. A similar trend was observed in 1991, with the deep placement of K resulting in a significantly lower volumetric soil moisture content as compared to the other treatments. At a depth of 8-16 inches in 1991, the surface broadcast application of 90 lb K_2O A^{-1} without in-row subsoiling had the highest volumetric soil moisture content. A lower volumetric soil moisture suggests that subsoiling and deep placement of K increased cotton root development at depths > 8 inches. In 1990, deep placement of K resulted in a significantly lower soil moisture content at the 16-32 inch depth as compared to all treatments which had not been subsoiled, as well as the treatment receiving 90 lb K_2O A^{-1} on the surface in combination with in-row subsoiling. At this depth (16-32 inches) during 1991, deep placement of K resulted in lower soil moisture as compared to the other treatments. The two treatments that were not subsoiled had the highest volumetric soil moisture content, suggesting that there was limited cotton root development at the 16-32 inch depth for the nonsubsoiled treatments.

The higher soil moisture contents in 1991 at depths below 8 inches in nonsubsoiled treatments (Fig. 1) are due in part to soil compaction. Soil penetrometer readings for the nonsubsoiled check treatment are presented in Fig. 2. Penetrometer readings taken in 5 inch increments out to 20 inches from the in-row position show a well developed traffic pan beginning at approximately 6 inches and extending to a depth of about 15 inches. The data in Fig. 2 shows the resistance to penetration was relatively uniform with respect to the distance from the in-row position. For the check treatment that was in-row subsoiled (Fig. 3), resistance to penetration was greatly reduced for the in-row position. In-row subsoiling reduced the resistance to penetration up to 10 inches out from the in-row position. This suggests that for subsoiled treatments there would have been less resistance for root penetration which led to a greater extraction of water at depths > 8 inches (Fig. 1).

Soil water extraction patterns with depth (Fig. 1) were corroborated by root length density data (Fig. 4). Cotton root density below the plow layer (8-32 inches) was increased by in-row subsoiling and the application of K fertilizer (Fig. 4). For the top 0-8 inches of soil there were no treatment effects on root density in 1990. In 1991, the highest root densities in the surface layer resulted from not subsoiling and the surface application of K. Higher root length densities in these treatments probably resulted from the stimulating effect of applied K on growth of the cotton root system above the traffic pan. In addition, the high density of the traffic pan (Fig. 2) would force a larger proportion of the root system to develop above the pan. At a depth of 8-16 inches in 1990, the check treatment without in-row subsoiling had a lower root density as compared to the other treatments ($P \leq 0.20$). Although there were no significant differences among the remaining 4 treatments, the treatment receiving the deep placement of K had the highest root density. As in 1990, at the 8-16 inch depth, treatments that were not in-row subsoiled had the lowest root density while the highest root density was obtained for the deep K treatment in 1991. At a depth of 16-32 inches there were no significant treatment effects in 1990, although the application of K, especially in combination with in-row subsoiling, tended to result in slightly higher root densities. In 1991, at a depth of 16-32 inches, the treatment receiving the deep applied K had a higher root density ($P \leq 0.20$) as compared to the two check treatments.

Plant weight just prior to maturity was highest for the surface broadcast application of 90 lb K_2O A^{-1} in combination with in-row subsoiling (Table 3). Whole plant weight was the lowest for the treatments that were not subsoiled. This shows that growth of the cotton plant was improved by in-row subsoiling and by the application of K fertilizer. The distribution of dry matter in the various plant parts, total leaf area and the leaf health index (LHI) showed similar trends. For stems, leaves, leaf area, and LHI, application of K on the surface in combination with in-row subsoiling resulted in higher values as compared to other treatments. However, for these parameters there were no statistical differences among the remaining treatments. Highest seed cotton yields for both years resulted from surface application of K in combination with in-row subsoiling (Table 3). As with whole plant weights, seed cotton yields were improved by a combination of subsoiling and the application of K, especially if surface applied. The surface applied K with in-row subsoiling resulted in a larger leaf surface area at the end of the growing season, and a larger proportion of the retained leaves were in a healthier condition.

Results of this study show that for a soil with a well developed traffic pan having medium soil test K in the surface and low soil test K in the subsoil, that in-row subsoiling and deep placement of K fertilizer increased cotton root development and soil water extraction below the plow layer. This increased rooting and water extraction was reflected in an increase in total plant weight by both subsoiling and the application of K fertilizer. From the stand point of K application, the deep placement of K resulted in greater soil water use and a higher root density below the plow layer as compared to the placement of K on the surface in combination with in-row subsoiling. However, these differences did not result in a yield improvement as reflected in the whole plant weight, leaf area, LHI and seed cotton yield data (Table 3). Although deep placement of K increased in-row cotton root length density and water use, the cotton root system was not obtaining enough K to meet its needs. The higher leaf surface area for the surface applied K treatment with in-row subsoiling would mean that more products of photosynthesis should be available for fruit development. Not only did this treatment result in a higher leaf surface area at the end of the season, but the leaves were also more healthy. Higher yields for the surface application of K with in-row subsoiling probably resulted since the surface applied K was exposed to a larger proportion of the cotton root system as compared to the deep placed K. The results of this and previous studies (8) suggest that for cotton growing on Alabama soils deep placement of K is not superior to surface broadcast applications of K.

Mention of a manufacturer does not indicate its approval by the USDA-ARS or by Auburn University at the exclusion of others.

References

1. Cassman, K. G., S. M. Brouder, B. A. Roberts, and D. C. Bryant. 1991. Cotton root growth in relation to localized nutrient supply, and residual value of potassium fertilizer as influenced by organic matter addition to vermiculitic soils. 1991 Res. Symp. Proc. Fluid Fertilizer Foundation. pp. 43-65.

2. Cope, J. T., Jr., C. E. Evans, and H. C. Williams. 1981. Soil test fertilizer recommendations for Alabama crops. Ala. Agric. Exp. Stn. Cir. 251.

3. DeRoo., H. C. 1956. Subsoiling, plowing and deep placement of lime or fertilizer in one operation. Agron. J. 48:476-477.

4. Doss, B. D., W. T. Dumas, and Z. F. Lund. 1979. Depth of lime incorporation for correction of subsoil acidity. Agron. J. 71:541-544.

5. Fehrenbacher, J. B., J. P. Vavra, and A. L. Lang. 1958. Deep tillage and deep fertilization experiments on a claypan soil. Soil Sci. Soc. Am. Proc. 22:553-557.

6. Gonzalez-Erico, E., E. J. Kamprath, G. C. Naderman, and W. V. Soares. 1979. Effect of depth of lime incorporation on the growth of corn on an oxisol of central Brazil. Soil Sci. Soc. Am. J. 43:1155-1158.

7. Khasawneh, F. E., and J. P. Copeland. 1973. Cotton root growth and uptake of nutrients: relation of

phosphorus uptake to quantity, intensity, and buffering capacity. Soil Sci. Soc. Amer. Proc. 37:250-254.

8. Mullins, G. L., C. H. Burmester, and D. W. Reeves. 1991. Cotton response to the deep placement of potassium on Alabama soils. 1991 Proc. Beltwide cotton Production research Conference. pp. 922-924.

9. Pearson, R. W., J. Childs, and Z. F. Lund. 1973. Uniformity of limestone mixing in acid subsoil as a factor in cotton root penetration. Soil Sci. Soc. Am. Proc. 37:727-732.

10. Reeves, D. W., J. H. Edwards, C. B. Elkins, and J. T. Touchton. 1990. In-row tillage methods for subsoil amendment and starter fertilizer applications to conservation-tilled grain sorghum. Soil and Tillage Research. 16:359-369.

11. Smucker, A. J. M., S. L. McBurney, and A. K. Srivastava. 1982. Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. Agron. J. 74:500-503.

12. Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63:995-1001.

13. Topp, G. C., and J. L. Davis. 1985. Measurement of soil water using time-domain reflectometry (TDR): A field evaluation. Soil Sci. Soc. Am. J. 49:19-24.

14. Topp, G. C., J. L. Davis, and A. P. Anna. 1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. Water Resour. Res. 16:574-582.

15. Tupper, G. R., and H. C. Pringle III. 1986. New equipment for deep banding dry lime into acid subsoils. 1986 Proc. Beltwide Cotton Production Research Conference. pp. 456-57.

16. Tupper, G. R, H. C. Pringle, III, and M. W. Ebelhar. 1988. Cotton response to deep banding dry fertilizer in the subsoil. 1989 Proc. Beltwide Cotton Production Research Conference. pp. 498-501.

17. Tupper, G. R., H. C. Pringle, III, and M. W. Ebelhar. 1989. Update on deep banding dry fertilizer in the subsoil. 1989 Proc. Beltwide Cotton Production Research Conference. pp. 498-501.

18. Woodhouse, W. W., Jr. 1956. Effect of placement and rate of phosphate, potash, and limestone on the growth of alfalfa and lespedeza. Soil Sci. Soc. Am. Proc. 20:15-18.

19. Woodruff, C. M., and D. D. Smith. 1947. Subsoil shattering and subsoil liming for crop production on claypan soils. Soil Sci. Soc. Am. Proc. 11:539-542.

Table 1. Initial chemical properties of the Norfolk soil

			Mehlich I Extractable			
Depth	CEC	pH	P	K	Mg	Ca
-inches-	meq/100 g		--------- lbs/acre			-------
0 to 6	4.77	7.0	92(H)[1]	91(M)	168(H)	730
6 to 12	4.84	6.2	84(H)	68(L)	78(H)	580
12 to 18	4.96	5.6	17(L)	84(L)	91(H)	550

[1] Soil test ratings by Cope et al. (2). VH = 'Very High'; H = 'High'; M = 'Medium'; L = 'Low'.

Table 2. Surface and deep fertilizer treatments used to evaluate soil water depletion and cotton root growth

Treatment No.	(Rip) Subsoil	K Rate	Fertilizer Placement
		-lbs K20/Acre-	
1-(Check)	No	0	---
2-(Check+SS)	Yes	0	---
3	No	90	Surface[1]
4	Yes	90	Surface
5	Yes	90	Deep[2]

[1] Potassium fertilizer broadcast on soil surface after in-row subsoiling and prior to secondary tillage.

[2] Deep placement - dry K fertilizer placed in a subsoil channel using a M. G. Dickey dry fertilizer applicator. Fertilizer was applied just prior to planting.

Table 3. Effect of subsoiling and deep placement of K fertilizer on seed cotton yields and the distribution of dry matter in the various plant parts.

	Cotton Yield		Dry Matter Distribution[1]					
Treatment	1990	1991	Plant	Bolls	Stems	Leaves	Leaf Area	LHI[2]
	---- lb/A ----		---------- grams/plant ---------				- square cm/plant -	
Check - SS	2140a[3]	2589a[3]	131b	82b	31b	18b	849b	2438b
Check + SS	2785b	2859ab	184ab	119ab	41b	24b	1298b	3352b
90 lb K20 - SS	2099a	3079ab	137b	81b	36b	20b	938b	2621b
90 lb K20 + SS	2834b	3292b	264a	138a	85a	41a	2011a	6002a
90 lb K20 Deep	2736b	2932ab	201ab	127ab	48b	26b	1281b	3187b

[1] For dry matter distribution data, means followed by different letters are significantly different at the 0.05 level of probability.

[2] LHI = Leaf Health Index. Leaf surface area calculated after weighting leaf surface area based on severity of K deficiency. Weight factors were: 5, healthy leaf; 4, slight deficiency; 3, moderate deficiency; 2 severe deficiency; 1, dead leaf.

[3] For seed cotton yield data, means followed by different letters are significantly different at the 0.10 level of probability.

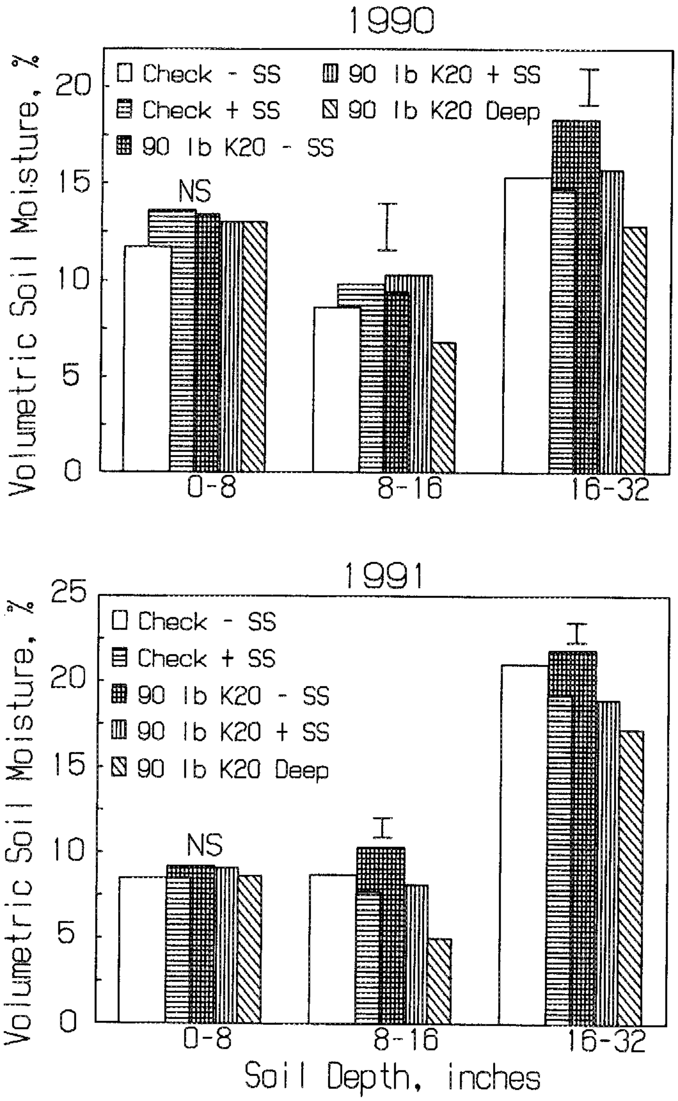

Figure. 1. Effect of in-row subsoiling and deep placement of K fertilizer on volumetric soil moisture content at three depths (0-8, 8-16, 16-32 inches) in a Norfolk soil. Error bars are the least significant difference (P = 0.10). NS = nonsignificant.

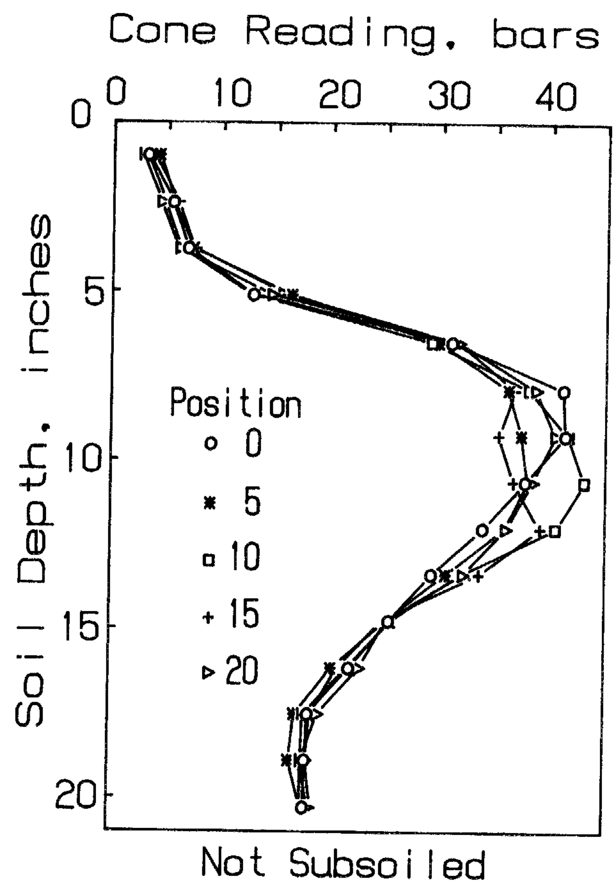

Figure. 2. Penetrometer readings in 1991 for the nonsubsoiled check treatment. Penetration position refers to the number of inches away from the in-row position.

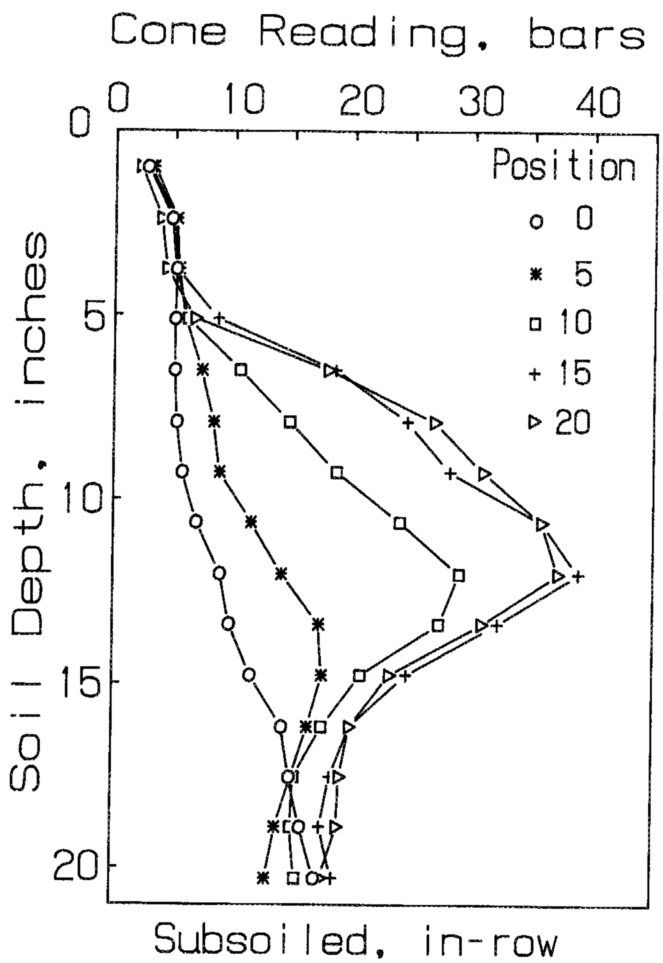

Figure. 3. Penetrometer readings in 1991 for the in-row subsoiled check treatment. Penetration position refers to the number of inches away from the in-row position.

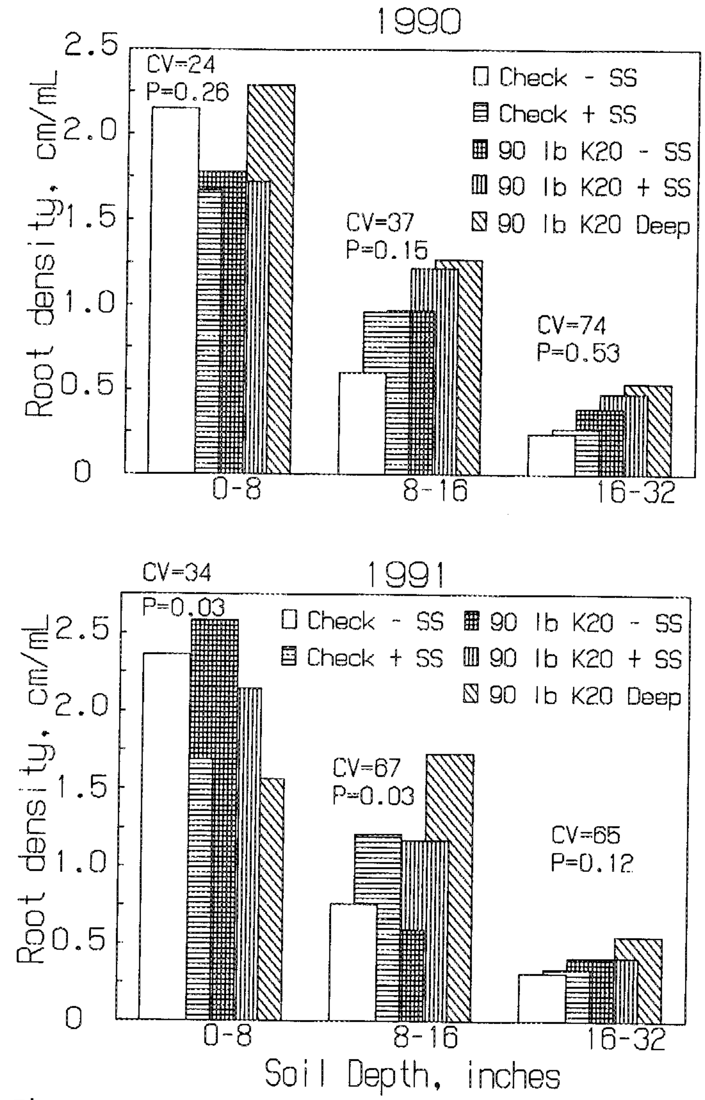

Figure. 4. Effect of in-row subsoiling and deep placement of K fertilizer on cotton root length density at three depths (0-8, 8-16, 16-32 inches) in a Norfolk soil. CV = coefficient of variation (5). P = probability level.